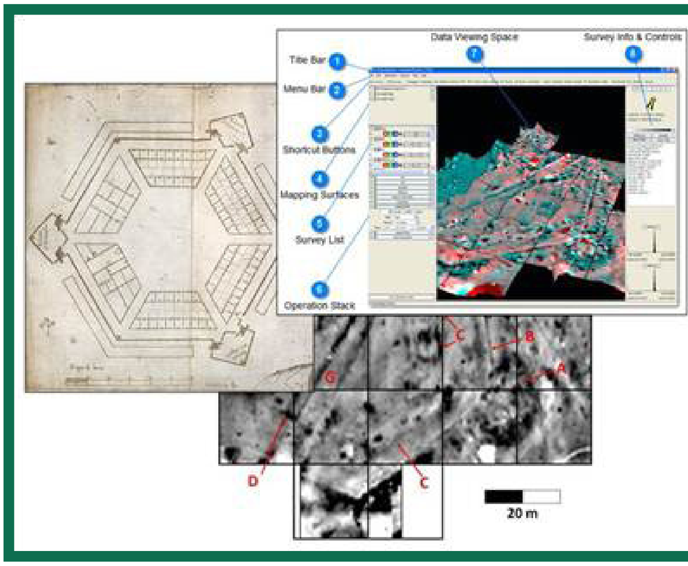
ESTCP
Cost and Performance Report

(RC-200611)



Streamlined Archaeo-Geophysical Data Processing and Integration for DoD Field Use

September 2012

ENVIRONMENTAL SECURITY
TECHNOLOGY CERTIFICATION PROGRAM

U.S. Department of Defense

COST & PERFORMANCE REPORT
Project: RC-200611

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ACRONYMS AND ABBREVIATIONS

2D	two-dimensional
3D	three-dimensional
bs	below surface
CAST	Center for Advanced Spatial Technologies
CFR	Code of Federal Regulations
COTS	commercial off-the-shelf
CR	cultural resource
CRM	cultural resource management
DoD	Department of Defense
EDM	electronic distance measurement
EMI	electromagnetic induction
ERDC	Engineer Research and Development Center
ESTCP	Environmental Security Technology Certification Program
FCC	Federal Communications Commission
GIS	geographic information system
GPR	ground penetrating radar
GSSI	Geophysical Survey Systems International
IDIQ	indefinite delivery, indefinite quantity
NAGPRA	Native American Graves Protection and Repatriation Act
NCPTT	National Center for Preservation Technology and Training
NHPA	National Historic Preservation Act
NRHP	National Register of Historic Places
NPS	National Park Service
SFASU	Stephen F. Austin State University
SHPO	State Historic Preservation Office
SERDP	Strategic Environmental Research and Development Program
TDY	temporary duty travel
UWB	ultra-wideband

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ACKNOWLEDGEMENTS

Many individuals and organizations contributed to the successful outcome of this project. The project (RC-200611) was funded by the Environmental Security Technology Certification Program (ESTCP). We thank ESTCP staff members Dr. John Hall, Mr. Pedro Morales, and Ms. Kristin Lau for their guidance and patience.

ArchaeoFusion was developed by a team at the University of Arkansas-Fayetteville Center for Advanced Spatial Technologies that was led by Dr. William Johnston and Dr. Fred Limp. Mr. Steve De Vore coordinated the National Park Service's (NPS) 2009 course in remote sensing held at Los Adaes, and served as one of the original members of the User Group who evaluated *ArchaeoFusion*. Other key members of the evaluation team were Dr. Kent Schneider (U.S. Forest Service, retired), Dr. Laurie Rush (U.S. Army, Fort Drum), and Mr. Scott Hall (U.S. Army Corps of Engineers, Walla Walla District). Dr. Lewis Somers (Geoscan Research USA) contributed his expertise with Geoscan Research's prototype MSP-40 cart-mounted resistance system and many other aspects of geophysical survey. Dr. Rinita Dalan, Mr. Dan Welch, Dr. Kris Lockyear, and other NPS instructors played important roles in the field demonstration and contributed field data. Dr. Jamie Lockhart (Arkansas Archaeological Survey) directed geophysical data collection prior to the NPS course and assisted with the field demonstrations. Dr. David Morgan co-sponsored the NPS course at Los Adaes and provided use of the National Center for Preservation Technology and Training conference facilities.

The Louisiana Division of Archaeology issued permits for the investigations at Los Adaes and their staff provided valuable help in the field. In particular, Mr. Jeff Girard contributed his survey skills and knowledge of local soils and archaeology. Mr. Ray Berthelot of the Louisiana Office of State Parks allowed us to work at Los Adaes, and the Los Adaes site managers helped us in many ways. Dr. Pete Gregory of Northwestern State University shared his extensive knowledge of Los Adaes and regional history and archaeology, as did Dr. George Avery (Stephen F. Austin University), who directed the ground truthing investigations. Mr. Bo Nelson and Mr. Mark Waters were skilled and tireless excavators.

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EXECUTIVE SUMMARY

OBJECTIVES OF THE DEMONSTRATION

Archaeological sites have cultural and scientific value, are widely distributed across the landscape, and can represent obstacles to training and infrastructure maintenance on Department of Defense (DoD) installations. Federal laws and DoD regulations require installations to identify sites, evaluate their eligibility for the National Register of Historic Places (NRHP), and either protect eligible and unevaluated sites or mitigate adverse effects caused by training and other Federal undertakings. Much of this work is based on manual labor by field and lab technicians. The current approach to compliance with these requirements is expensive, time-consuming, and a potential source of conflict with Native Americans and other stakeholders.

The objectives of this project were to: 1) introduce the integrated multi-sensor approach for detecting and characterizing subsurface deposits at archaeological sites; 2) create *ArchaeoFusion*, a new user-friendly software that serves as the approach's technology infusion tool; and 3) demonstrate and validate the cost and performance benefits of the approach and *ArchaeoFusion* to DoD geophysical users, Federal, state, and tribal historic preservation offices, resource managers, and other cultural resource management (CRM) practitioners. Use of the integrated multi-sensor approach will reduce costs and invasiveness and increase the reliability of information about subsurface deposits.

TECHNOLOGY DESCRIPTION

The integrated multi-sensor approach is a method for detecting and characterizing the nature of subsurface archaeological deposits. Information about such deposits is essential for determining a site's NRHP eligibility and mitigating sites that represent serious obstacles to military undertakings in a cost-effective, responsible manner. The approach is based on the integration (fusion) of data collected using a suite of near-surface sensor types. This project developed *ArchaeoFusion*, which when used in conjunction with one or more sensors enables individuals with modest technical expertise and experience to achieve all of the data collection, processing, integration, and interpretation tasks necessary to use the integrated multi-sensor approach.

The technically and methodologically theoretical basis for the integrated multi-sensor approach is the finding in Strategic Environmental Research and Development Program (SERDP) Project RC-1263 that multiple sensors, when properly processed and integrated, can 1) provide information about subsurface deposits that enhance the reliability and reduce the cost and invasiveness of investigations needed to characterize the nature and condition of archaeological subsurface deposits and 2) facilitate evaluating site NRHP eligibility status. SERDP Project RC-1263 identified many effective techniques for data integration, but also found that the integrated multi-sensor approach had labor and technical expertise requirements that precluded implementation by CRM programs at DoD installations.

This project's field component was conducted in conjunction with the National Park Service's (NPS) 2009 introductory course in remote sensing held at Presidio Los Adaes, the project demonstration site. Located in west-central Louisiana, Los Adaes is a State Historic Site that includes the well-preserved subsurface remains of an 18th century Spanish military outpost. The

field component demonstrated all aspects of geophysical collection using five sensor types. This project also demonstrated and quantified the extent to which *ArchaeoFusion* provides all of the data processing, integration, and interpretation capabilities required by novice and expert users to achieve the benefits of the integrated multi-sensor approach. Eight performance objectives were developed to assess *ArchaeoFusion's* benefits in terms of the: 1) number of anomalies detected; 2) effectiveness of its "wizards" (processing guidance for novice users); 3) advantages over commercial off-the-shelf (COTS) software; 4) time required for processing data and recording metadata, using diverse processing and integration techniques with no loss of data resolution; and 5) providing a basis for correctly assigning anomalies to archaeological feature categories.

DEMONSTRATION RESULTS

Because of an initial difficulty in achieving detailed written feedback from individuals who had volunteered to evaluate *ArchaeoFusion*, the evaluation of the performance objectives used written information collected from 14 evaluators through an online survey. Survey respondents rated their level of agreement or disagreement with eight different statements that closely mirrored the original performance objectives. The rate of agreement ranged from 46 to 100%, with an average of 80%. Results strongly support the integrated multi-sensor approach and the use of *ArchaeoFusion* as the technology infusion tool.

IMPLEMENTATION ISSUES

Costs associated with implementation of the approach include purchase of *ArchaeoFusion* (free to DoD users); supplemental graphic software (less than $2,000); up to five sensors (at approximately $20,000 each); and labor, tuition, and travel associated with training and geophysical survey. Initial implementation costs can be offset relatively quickly by savings associated with use of the integrated multi-sensor approach to evaluate several relatively complex sites or by the mitigation of a single relatively complex site.

Installations considering adoption of this strategy should first ensure that they have a considerable number of relatively complex sites that are amenable to geophysical survey. These sites should likely include discrete features, whose NRHP-status needs to be evaluated, and that represent serious obstacles to the mission and therefore need to be properly removed (mitigated). Future reductions in funds available to manage cultural resources on DoD installations may make it more cost effective for installations to require private sector firms who conduct their site evaluations to employ the integrated multi-sensor approach. This would transfer start-up costs to the private firms but would still allow DoD to realize the cost and performance benefits that accompany use of the integrated multi-sensor approach.

Technology transition efforts include broad dissemination of a concise summary of the integrated multi-sensor approach and *ArchaeoFusion's* capabilities and benefits. Articles in professional peer-reviewed journals will reach targeted audiences in archaeology, computer science, and land/resource management. The Center for Advanced Spatial Technologies (CAST) will make *ArchaeoFusion* available at no cost to DoD users for 5 years, and provide on-line support in the use of *ArchaeoFusion*. Periodic updates and expansions in *ArchaeoFusion's* capabilities are planned and will be announced on the CAST website.

1.0 INTRODUCTION

1.1 BACKGROUND

A major component of the CRM work conducted on military installations in compliance with Federal law (the National Historic Preservation Act [NHPA] of 1966, as amended) is the evaluation of prehistoric and historic archaeological sites for NRHP eligibility. Archaeological sites are numerous and widely distributed across the landscape, and often represent obstacles to realistic military training. Some sites have important cultural and/or scientific value and those with good integrity (minimally disturbed deposits) are often eligible for nomination to the NRHP. Sites whose eligibility status has not been determined must be avoided, and impacts to eligible sites can result in requirements for expensive mitigation. Often, mitigation involves a program of data recovery based on hand excavation, analysis and dissemination of results, and long-term curation of artifacts under specified conditions. Traditional methods for site evaluation and mitigation are still based on hand excavation by skilled field technicians and are therefore costly, invasive, time consuming, and potentially unreliable.

A SERDP project completed in 2006 (SI-1263, *New Approaches to the Use and Integration of Multi-Sensor Remote Sensing for Historic Resource Identification and Evaluation* [Kvamme et al., 2006]) developed methods that provide exceptionally detailed, remotely sensed images of the subsurface, permitting accurate characterization of archaeological deposits for a wide range of sites. That research demonstrated that remote sensing (including satellite, aerial, and ground-based geophysical sensors) can produce a level of information about subsurface deposits far richer than that provided by traditional approaches. Use of an integrated multi-sensor approach can reduce costs and invasiveness, and improve information return and reliability. The underlying "theory" of this approach is that multiple integrated data sets provide a more nuanced, complete image of subsurface archaeological deposits, providing the basis for sounder and more cost-effective decisions about resource management. However, the extensive amount of time required to manually process and integrate (combine into one) data produced by each instrument is a primary obstacle to much broader adoption and effective use of the integrated multi-sensor approach.

This ESTCP project demonstrated the new technology in two phases. Phase 1 demonstrated that the *ArchaeoFusion* software (the technology's infusion tool) is capable of performing all the tasks required to process, integrate, and interpret geophysical data. *ArchaeoFusion's* capabilities were initially demonstrated during a beta-test of the software conducted in November, 2008. Phase 2 demonstrated all aspects of a multi-sensor geophysical site evaluation, including instrument set-up and preparation, field data collection, data processing and integration using *ArchaeoFusion*, interpretation of the data in terms of archaeological features and other deposits, and the benefits in improved decision making and cost reduction to DoD programs. Ground truthing excavations were conducted to demonstrate the extent to which interpretations of the geophysical data permitted accurate characterization of subsurface deposits (i.e., assigning anomalies to archaeological feature categories). Phase 2 continued through September, 2011.

1.2 OBJECTIVES OF THE DEMONSTRATION

This project had two fundamental objectives. The first was to demonstrate to a broad audience of CRM professionals the benefits of the integrated multi-sensor geophysical approach

(implemented using *ArchaeoFusion*) to characterizing subsurface archaeological deposits. Eight performance objectives were defined to demonstrate *ArchaeoFusion's* capabilities in terms of the number of anomalies detected, the effectiveness of its "wizards" (processing guidance for novice users), the time required for processing data and recording metadata, using diverse processing and integration techniques with no loss of data resolution, and providing a basis for correctly assigning anomalies to archaeological feature categories. Responses from 14 software evaluators to a series of questions indicated that all of the performance objectives were satisfactorily met. More detailed information on results from the demonstration at Los Adaes is provided in the project's Final Report, a number of presentations at professional conferences, and forthcoming articles in professional journals.

The second objective was to achieve a much wider use of the approach by DoD CRM programs, including their in-house personnel and/or the private firms that execute much of the archaeological site evaluation work on DoD installations. This has not yet been achieved, as several important products have not yet been distributed. Articles in professional journals have not yet been completed. We believe that the single-most effective product will be a very widely distributed, brief, well-illustrated summary of the integrated multi-sensor approach, *ArchaeoFusion's* capabilities, and results of the geophysical and ground-truthing investigations at Presidio Los Adaes.

1.3 REGULATORY DRIVERS

The NHPA of 1966, as amended, and its implementing regulations (36 Code of Federal Regulations [CFR] 800) require Federal agencies to take into account the effects of their undertakings on historic properties (including archaeological sites) that are or may be eligible for the NRHP. The Native American Graves Protection and Repatriation Act (NAGPRA) (Public Law 101-601; 25 U.S.C. 3001-3013) specifies that planned excavations that may result in the discovery of human remains must be conducted under permit and only after consultation with appropriate Native American groups. NAGPRA does not come into play for most archaeological sites, but failure to comply with its requirements can lead to high-profile disputes with stakeholders, delays to training, and negative impacts to DoD's public image as a responsible steward of public and tribal lands. Army Regulation 200-1 *Environmental Protection and Enhancement* (revised 13 December, 2007) provides the framework for the Army's environmental management program. It specifies that the objective of CRM is to implement procedures to protect against encumbrances to the mission by ensuring that all installations manage cultural resources effectively (including compliance with NHPA, NAGPRA, and other Federal laws and regulations).

2.0 TECHNOLOGY/METHODOLOGY DESCRIPTION

2.1 TECHNOLOGY/METHODOLOGY OVERVIEW

2.1.1 Theory

The integrated multi-sensor geophysical approach is based on the “theoretical”(or perhaps more accurately, methodological) finding (Kvamme, et al. 2006) that data from a suite of sensors (ground penetrating radar [GPR], magnetometry, electrical resistance, induced electrical conductivity, and magnetic susceptibility), when properly processed and integrated, yield images of subsurface deposits that are of considerable value to cultural resource managers (Figure 1, a-c). In most cases, geophysical surveys target potentially important, discrete deposits that archaeologists refer to as “features,” including constructed facilities such as houses, pits and graves, and unintentional concentrations of materials (e.g., pottery or food residues) that result from particular activities. Features provide important information about the nature of activities conducted at a site, and often contain artifacts or other materials that indicate when a site was occupied. Use of geophysics can enhance the reliability and reduce the invasiveness and cost of investigations needed to characterize the nature and condition of an archaeological site’s subsurface deposits, and to evaluate the site’s NRHP eligibility status.

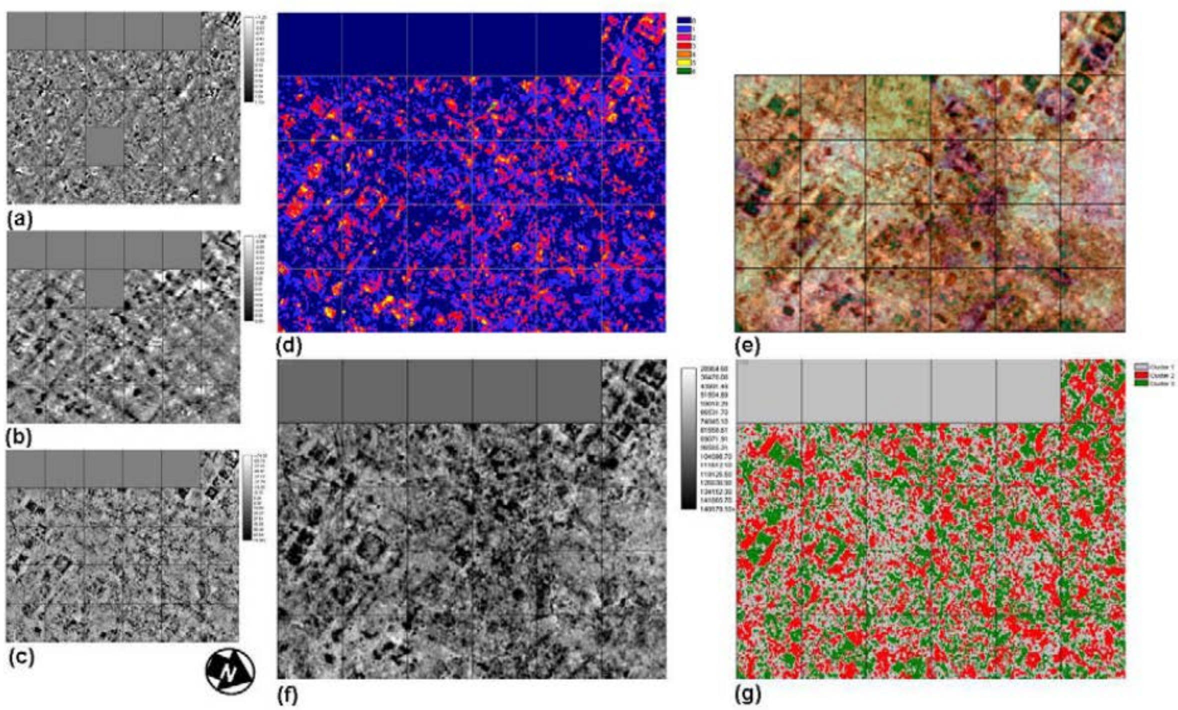

Figure 1. Selected geophysical data layers and integration outcomes.
Figure 1 shows selected geophysical data layers and integration outcomes exemplified with SI-1263’s Pueblo Escondido geophysical survey. The images are: (a) magnetic gradiometry, (b) magnetic susceptibility, (c) one of four ground penetrating radar slices, (d) integration of results by adding together binary representations of significant anomalies from each data layer, (e) color translucency overlay of ground penetrating radar (tinted red), soil conductivity (green), and magnetic susceptibility (blue), (f) mathematical product of all layers, and (g) three-cluster solution of unsupervised classification of all data layers.

Data integration or fusion implies the use of various graphical, mathematical, and statistical algorithms to combine multiple images into one product whose data content is better or more useful than any of its constituents (Figure 1, d-g). Use of multiple sensors in remote sensing investigations of archaeological sites is highly desirable because the various sensors respond to different physical properties of the archaeological record and surrounding soil. At one site, for example, GPR may detect features not detected by magnetometry. At a second site, features detected by electrical resistance may not be discernible in the GPR data. These differences are associated with variability among sites in the presence and interaction of soil texture, moisture, mineralogical, and other conditions that cause subsurface features to contrast with their immediate surroundings. Because subtle differences in properties and interaction among properties can affect contrast, it is often difficult even for experienced practitioners to predict which sensors will be most useful at a particular site. Using multiple sensors increases the likelihood that at least some of the features that are present will be detected, and often provides more information about the features. Therefore, optimization of a remote sensing investigation typically requires use of *at least* several different instruments and processing tools. The integrated approach demonstrated here offers a means of optimizing the use and information return of multiple sensors.

This ESTCP project has developed *ArchaeoFusion*, a new, user-friendly software tool that allows a wide range of users (ranging from novice to expert) to implement the approach and achieve its benefits in terms of increased reliability, reduced invasiveness and costs. In short, *ArchaeoFusion* serves as the technology's infusion tool.

Figure 2 presents a flow diagram for the integrated multi-sensor approach. Data from multiple sensors are downloaded to *ArchaeoFusion*, where they are processed, integrated, and interpreted. Images are then exported to geographic information system (GIS) or other graphic software where they are labeled and finalized for inclusion in a report.

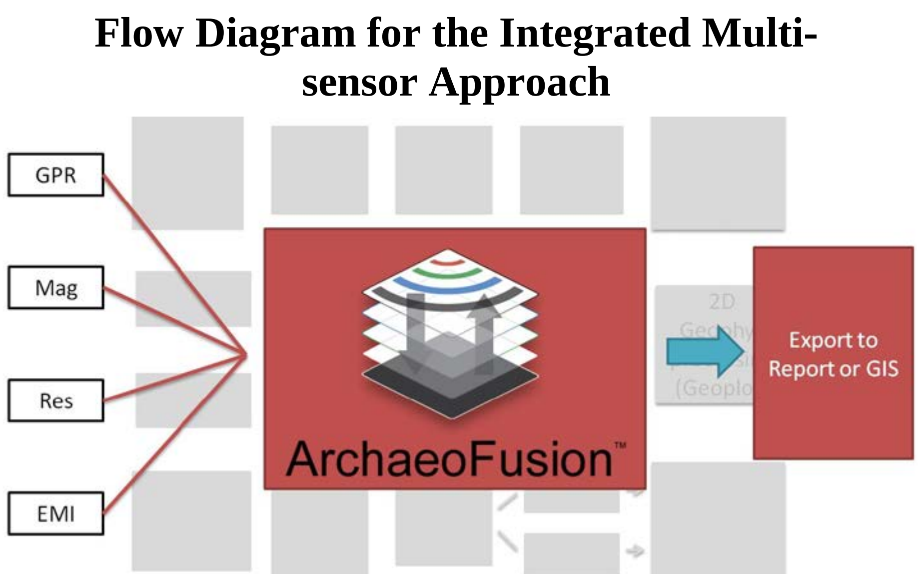

Figure 2. Flow diagram for the integrated multi-sensor approach.

2.1.2 Operation

ArchaeoFusion provides for a full range of data processing and integration options for the expert user as well as pre-loaded macros designed to guide novice and intermediate practitioners through the processing steps. Substantial benefit has been realized in streamlining GPR processing, but cost savings have been realized for the processing, integration, and fusion of data collected from all supported sensors. *ArchaeoFusion* maintains all data in a single software environment while preserving spectral resolutions and recording processing steps for metadata documentation (Figure 2).

ArchaeoFusion is designed as a platform to integrate, as much as possible, the various processes required in a multi-sensor survey approach. The graphical user interface is written in Java 1.5 using the Swing, Java OpenGL, and Java Advanced Imaging Library components. All processing operations are coded in Matlab 7.1 and its Image Processing, Signal Processing, and Curve Fitting Toolboxes.

Within *ArchaeoFusion*, all work is organized into various projects. Projects are stored as combination ASCII and binary files comprising data collected from various instruments at one or more sites and all the operations used to process this data. The interface to the project file (i.e., *ArchaeoFusion* itself) consists of two primary components. The Survey Tool (Figure 3) is used to load data in multiple formats, arrange the “tiles” of data (e.g., the data collected in one of a series of small blocks of various sizes and shapes) into a single “survey” and provide access to utilities designed to correct geometric (or data placement) errors associated with sample rates and instrument malfunction. The survey itself is positioned and oriented within a global reference frame using external data input by the user. Once assembled and assigned global coordinates, the survey is added to the project and loaded into the Main Window (Figure 4) as a new layer. This interface provides access to general and data specific processing tools that can be assembled into an “operation stack”, in which a series of sequential operations are defined and run in a single step. Each survey will have a unique chain constructed by the user.

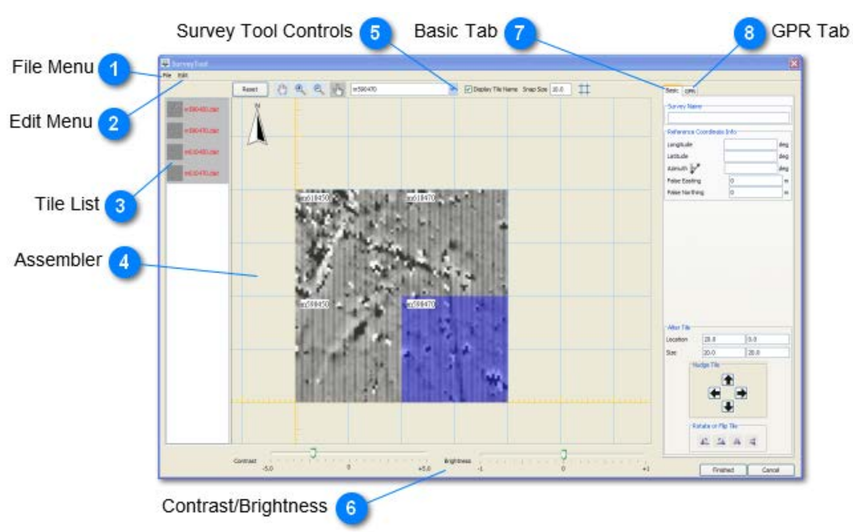

Figure 3. *ArchaeoFusion*’s Survey Tool contains all tools needed to import and assemble individual data tiles into site-wide surveys.

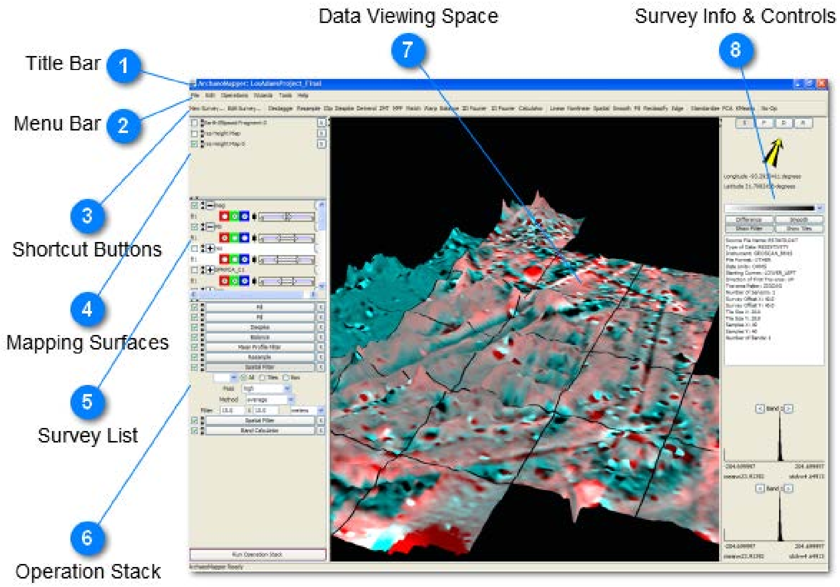

Figure 4. Main *ArchaeoFusion* viewing window and processing environments.

Novice users will take advantage of pre-loaded macros, which are saved operation stacks that are designed to yield acceptable results in most circumstances. If the user is not satisfied with the results, any parameter within the chain may be modified to see its effect on the final processed image. If GPR data are included in the project, the GPR Loader (Figure 5) facilitates each step of data processing, beginning with loading individual reflection profiles and including filtering, gaining, calculating velocity, and slicing. A three-dimensional (3D) cube is created and then sliced, creating a multi-band image for processing with other two-dimensional (2D) data. The data cubes can be re-sliced using different algorithms and thicknesses at any time.

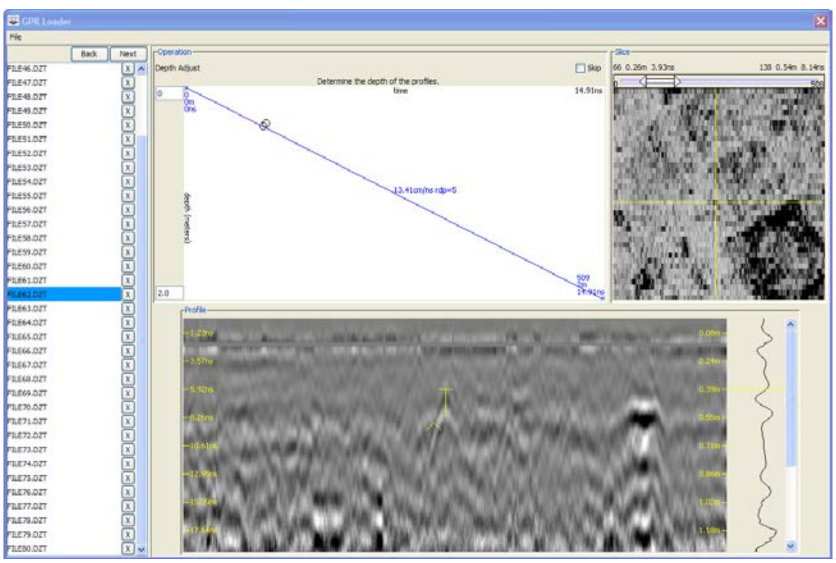

Figure 5. The GPR Loader guides users through processing GPR data and creating 2D slice images.

As multiple layers (or surveys) are added to the layer stack, fusion operations become active. The operations range from simple interactive color composite and translucent display, to "band-math" operations (e.g., add 10% of layer 1 to 90% of layer 3 and display the logarithm base 2 of the result), to sophisticated statistical operations such as principal component analysis. The viewing environment is natively 3D, so that layers may be viewed from a variety of viewpoints and overlaid on digital elevation data available from any source.

2.2 DEVELOPMENT OF THE APPROACH

Remote sensing (a term widely, if imprecisely, used synonymously with "geophysical") techniques have been used in archaeological investigations for many years. Aerial photography came into use by archaeologists shortly after the First World War. Two techniques that have proven to be of great value for archaeology—electrical resistance and magnetometry—were pioneered in the United Kingdom. Electrical resistance was first used at an archaeological site in 1946 by Richard Atkinson (Atkinson, 1953; Clark, 2001; Gaffney and Gater, 2003), and Martin Aitken used a proton magnetometer to detect kiln and earth-filled pits in the United Kingdom as early as 1958 (Atkinson, 1953; Clark, 2001; Gaffney and Gater, 2003).

Despite important pioneering work by John Weymouth, Bruce Bevan, and others, geophysical techniques were not widely used in the United States until advances in information technology made it possible to record and map the relatively high density data needed to detect very low contrast feature types like earth-filled pits. There are now at least some archaeo-geophysical practitioners in most states, and articles documenting successful surveys have appeared in a number of professional journals and at many conferences. Despite this progress, most established archaeologists in the United States have not used geophysics. State Historic Preservation Offices (SHPO) typically do not yet recognize geophysical techniques as a viable alternative to traditional excavation, and geophysics is not well integrated into CRM.

2.3 DEVELOPMENT OF THE APPROACH IN THIS PROJECT

SERDP Project SI-1263, led by Ken Kvamme and Fred Limp, demonstrated that the potential benefits of an approach based on the integration of data from a suite of geophysical sensors included increased information return and reliability and decreased invasiveness and (in many cases) cost (Kvamme et al., 2006). The present ESTCP project is, in many ways, a follow-up to the SERDP effort. Major advances to the integrated multi-sensor approach that have been made by the present ESTCP project include development of 1) *ArchaeoFusion* software to serve as the technology infusion medium; 2) an extensive user's manual; 3) a separate monograph (Ernenwein and Hargrave, 2007) that provides detailed guidance on the selection and use of geophysical sensors; 4) a field demonstration of the integrated approaches' cost and performance benefits; and 5) the (ongoing) wide dissemination of the information about the ESTCP project in particular and the integrated multi-sensor approach in general.

The *ArchaeoFusion* user's manual is an extensive, well-illustrated, web-based guide to all aspects of the software's use. The guidance document (*Archaeological Geophysics for DoD Field Use: A Guide for New and Novice Users* [Ernenwein and Hargrave, 2007]) is available via the ESTCP web site. It provides detailed but largely non-technical discussions of the core techniques (electrical resistance and conductivity, magnetic gradiometry and susceptibility, and

GPR), issues to consider (e.g., features, vegetation, recent impacts, time, cost) in selecting a technique for particular sites and for establishing in-house geophysical programs in various geographic regions, and integrating the multi-sensor approach into existing CRM programs.

2.3.1 Expected Applications of the Technology

Archaeological investigations executed in compliance with Section 106 of the NHPA are generally divided into three phases: 1) field surveys (and archival searches) undertaken to discover sites, 2) NRHP eligibility evaluations (generally based on test excavations), and 3) mitigation of unavoidable adverse impacts to NRHP-eligible sites. Geophysical survey can be very useful in NRHP evaluations, particularly if the site in question is large and/or complex, or if special circumstances (such as the possible presence of Native American burials) argue against excavation. It is in the area of planning for site mitigation where the benefits of geophysical survey can be the greatest. Mitigation of damage to archaeological sites typically includes large-scale hand excavation, analysis of the artifacts recovered, publication of results, and long-term curation of artifacts and records. Effective use of geophysics can target excavation units on important or representative areas, reducing the overall amount of excavation needed, as well as costs associated with analysis and curation.

2.4 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY/ METHODOLOGY

2.4.1 Traditional Approach

Fieldwork conducted to evaluate a site using the traditional approach varies from state to state, but often includes a surface inspection and artifact collection. Inadequate surface visibility often leads to the excavation of shovel tests intended to identify horizontally extensive intact cultural strata such as a lens of midden below the uppermost disturbed stratum. Often a small number of small (e.g., 1 by 1 m) test units are excavated using shovels and trowels, screened, profiled, and documented. The greatest weakness of the traditional approach is that the excavations expose a tiny proportion of the site's total area, making it highly unlikely that one will encounter features, which are generally small and often widely spaced. Advantages of this traditional approach include its familiarity and acceptability to many SHPOs and other stakeholders, and the fact that it can be done by nearly all archaeologists. The traditional approach offers the lowest cost option for evaluating *individual* sites that are small, very heavily disturbed, or where vegetation precludes geophysical survey.

Geophysical survey can be very useful in NRHP evaluations, particularly if the site in question is large and/or complex, or if special circumstances (such as the possible presence of Native American burials) argue against excavation. Where site conditions permit its use, geophysics allow one to examine very large portions of sites, dramatically increasing the likelihood of recovering reliable information about the presence, density, and distribution of subsurface features. It is in the area of planning for site mitigation where the benefits of geophysical survey can be the greatest. Mitigation of damage to archaeological sites typically includes large scale hand excavation, analysis of the artifacts recovered, publication of results, and long-term curation of artifacts and records. Effective use of geophysics can target excavation units on important or representative areas, reducing the overall amount of excavation needed, as well as

costs associated with analysis and curation. Use of the integrated multi-sensor approach will make it feasible for installations to responsibly mitigate (remove) sites that represent serious obstacles to training or infrastructure expansion.

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3.0 PERFORMANCE OBJECTIVES

3.1 ASSESSMENT 1

Eight performance objectives were defined to demonstrate *ArchaeoFusion's* core capabilities and the extent to which it permits an effective implementation of the integrated multi-sensor approach. An initial performance assessment (Assessment 1) conducted during the first quarter of 2011 failed to elicit an adequate number of responses from a relatively large group of individuals (n=53) who had volunteered to participate in the software evaluation. In retrospect, Assessment 1's data processing exercise using *ArchaeoFusion* required too much uncompensated labor for most participants. Many of the participants provided enthusiastically positive feedback, but did not complete the evaluation. A revised approach (Assessment 2) was then used as noted below.

3.2 ASSESSMENT 2

Table 1 provides the performance objectives and results for Assessment 2. A detailed analysis of these results is given in section 6: Performance Assessment.

Table 1. Performance objectives and results summary for Assessment 2.

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives				
1. Non-integrated multi-sensor surveys provide more useful information than single sensor surveys	Responses to Survey Question #1.	Participant must have general knowledge of archaeological geophysics.	Greater than 50% agreement	100% agreement
2. Data integration increases potential for detecting archaeological features when compared to non-integrated data	Responses to Survey Question #2.	Same as above.	Greater than 50% agreement	100% agreement
3. *ArchaeoFusion* allows data integration	Responses to Survey Question #3.	Participant must have experience integrating data in *ArchaeoFusion*.	Greater than 50% agreement	92% agreement
4. Data processing using *ArchaeoFusion* is faster and easier than using COTS software	Responses to Survey Question #7.	Participant must have experience processing data in *ArchaeoFusion* and other comparable software.	Greater than 50% agreement	61% agreement
5. Data from all major sensor types can be adequately processed using only *ArchaeoFusion*	Responses to Survey Question #4.	Participant must have experience processing all major data types in *ArchaeoFusion*.	Greater than 50% agreement	46% agreement

Table 1. Performance Objectives and Results Summary for Assessment 2 (continued).

Performance Objective	Metric	Data Requirements	Success Criteria	Results
Qualitative Performance Objectives (continued)				
6. *ArchaeoFusion* preserves data resolution throughout processing	Responses to Survey Question #6.	Participant must check the resolution of their data in *ArchaeoFusion* before and after processing.	Greater than 50% agreement	100% agreement
7. *ArchaeoFusion* reduces the time needed and increases the consistency and quality of metadata	Responses to Survey Question #5.	Participant must have experience processing data in *ArchaeoFusion* and other comparable software.	Greater than 50% agreement	54% agreement
8. Ground truthing enhances the usefulness of geophysical data	Responses to Survey Question #8.	Participant must have experience ground-truthing geophysical data.	Greater than 50% agreement	86% agreement

Assessment 2 consisted of an online survey (http://www.surveymonkey.com/s/S5YL22D) and a simplified version of the same tutorial and processing exercise used in Assessment 1. The survey asked respondents to rate their level of agreement or disagreement with a series of statements, which mirrored the original eight Performance Objectives (the questions are presented in section 6). The last question requested comments about advantages and shortcomings of *ArchaeoFusion*. Users could answer these questions based on experience they already had using *ArchaeoFusion*, or by following along with the tutorial, which simultaneously helped them learn the software.

4.0 SITE DESCRIPTION

4.1 SITE LOCATION AND HISTORY

Los Adaes State Historic Site (16NA16), located near Robeline, (west-central) Louisiana, served as the project demonstration site (Figure 6). A site not located on a military installation was used to ensure that unforeseen increases in security would not preclude participation by a wide range of non-military personnel. Los Adaes includes the archaeological remains of a presidio (or fort), mission, and settlement established by the Spanish in 1721, shortly after the appearance of a French trading post in nearby Natchitoches, Louisiana (Gregory et al., 2004). The field demonstration focused on the fort and immediately adjacent portions of the associated 18th century settlement.

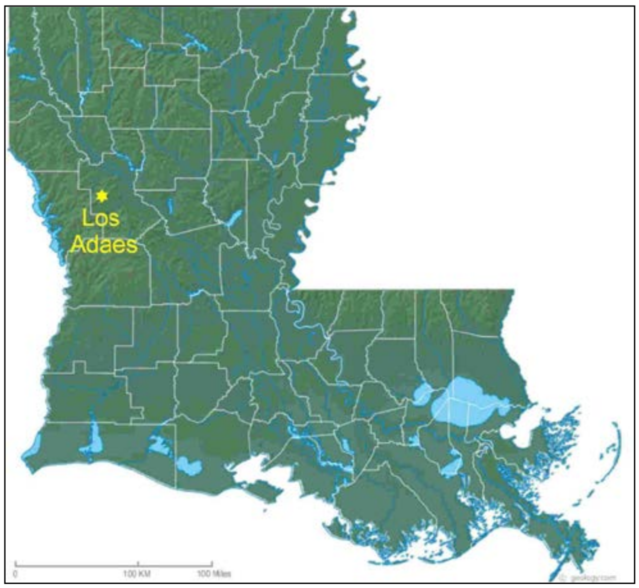

Figure 6. Location of Los Adaes State Historical Site in west-central Louisiana.

4.2 SITE CHARACTERISTICS

Two historic maps of Los Adaes have survived: an architectural plan that dates to 1720 and conveys the fort's intended design and a very detailed map drawn in 1767 during a military inspection (Gregory et al., 2004) (Figure 7). The 1767 map also includes a diagram showing the facades of a number of the fort's structures. The 1767 map as well as the results of previous excavations provided additional support for the existence of a very wide range of feature types. The excavations provided detailed information about feature depth, artifact contents, and other factors that helped interpret the geophysical results.

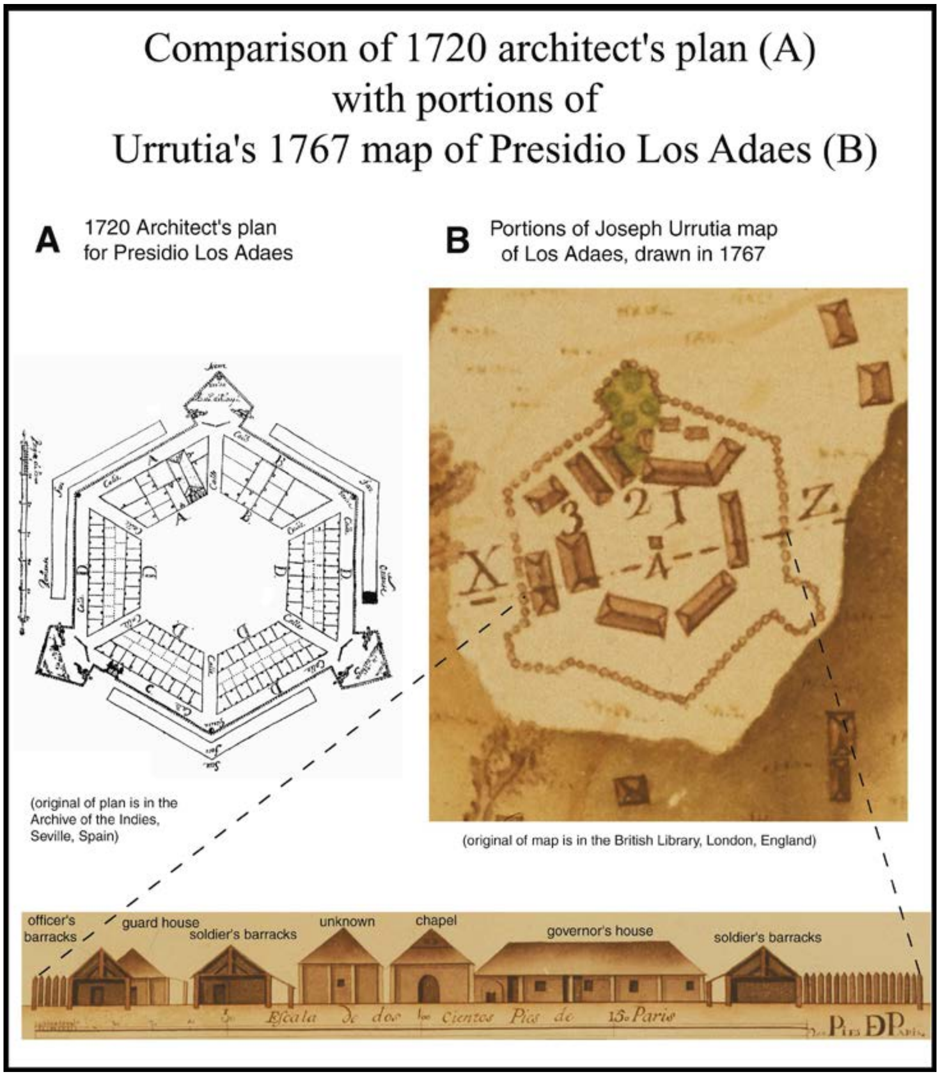

Figure 7. Architectural plan ca. 1720 (left), an excerpt of the 1767 map (right), and drawing of building facades along the XZ axis.

Los Adaes offered favorable conditions for geophysical survey as well as for field demonstrations associated with the 2009 NPS class. The site includes a small museum with interpretive exhibits, restrooms, and water and power needed for water screening during the ground truthing component. The grass was regularly mowed, and scattered trees provided welcome shade for informal lectures and discussions. The only serious obstacle to geophysical survey was an arrangement of horizontal wood beams held in place by iron rebar. The beams served to provide site visitors with an idea of the fort's six-sided layout, but represented a source of massive magnetic "clutter" (anomalies that complicate detection and interpretation of the targeted deposits) and represented obstacles for pedestrian survey and cart-mounted sensors. The site staff temporarily removed the beams and rebar shortly before the NPS class and ESTCP demonstration.

5.0 TEST DESIGN

5.1 CONCEPTUAL TEST DESIGN

This project's main objectives are listed below and broken down into the following steps:

1. Project Objective 1 was to create *ArchaeoFusion*, a new user-friendly software that allows individuals with relatively modest levels of expertise and experience to accomplish the data processing required by the integrated multi-sensor approach.
    a. *ArchaeoFusion* Alpha Design
    b. *ArchaeoFusion* Beta Test Design
    c. Ongoing testing and development of *ArchaeoFusion*
2. Project Objective 2 was to demonstrate and validate the cost and performance benefits of the approach and technology infusion tool (*ArchaeoFusion*) to DoD geophysical users, representatives of Federal, state, and tribal Historic Preservation offices, Federal and state resource managers, and other CRM practitioners. Steps b-e were accomplished during the field demonstration at Los Adaes State Historic Site.
    a. Beta test of *ArchaeoFusion.*
    b. Multi-sensor survey of a complex archaeological site (Los Adaes State Historic Site, Louisiana).
    c. Processing and integration of the Los Adaes geophysical data using *ArchaeoFusion*.
    d. Make predictions about the nature of subsurface features at Los Adaes.
    e. Test these predictions with ground-truth excavations. An independent evaluation of those predictions by means of small-scale, carefully targeted excavations.
    f. Presentation and dissemination of results.

5.2 BASELINE CHARACTERIZATION AND PREPARATION

5.2.1 Preliminary Survey

A preliminary geophysical survey was conducted at Los Adaes in early September, 2008. The objective was to ensure that Los Adaes would provide a good opportunity to demonstrate the integrated multi-sensor approach and *ArchaeoFusion's* capabilities. Results of that survey verified that the site's deposits were amenable to geophysical survey, and thus, adequate to meet the field demonstration's needs. The preliminary magnetic gradient, magnetic susceptibility, electrical resistance and conductivity surveys produced high quality data. A number of anomalies related to the fort were apparent and this corroborated assessments based on previous excavations that the site's deposits exhibit good depositional integrity. GPR data were less informative but it was hoped that better results could be achieved during the demonstration survey. Magnetic clutter associated with naturally occurring "ironstone" and late 19th and 20th century occupations was present but did not seriously complicate interpretation of the data.

5.2.2 Site Preparation

Several tasks were accomplished to prepare the site for the field demonstration. A metric grid comprised of 21.5, 20x20 m squares was established that included all but the heavily wooded western-most portions of the fort. The horizontal wood beams held in place with rebar were temporarily removed by the site managers. Following the geophysical survey, an electronic distance measurement (EDM) was used to establish two corners of each of the 1x1 m units selected for excavation. Two highly experienced excavators were hired. Hand tools, hoses with high-pressure nozzles, and buckets to move excavated soil to the water screens were brought to the site. Water screening was done adjacent to a deck the protruded off the museum building.

5.3 DESIGN AND LAYOUT OF TECHNOLOGY AND METHODOLOGY COMPONENTS

Technology components used in this project included *ArchaeoFusion* and several geophysical sensors used during the preliminary and demonstration surveys. *ArchaeoFusion* is thoroughly described in the Final Report (Ernenwein et al., 2012), so here we focus on the geophysical instruments. Each of the geophysical techniques used at the site can be viewed as a treatment, although that term is rarely used in archaeo-geophysics. There is no good analog for a control, other than the opportunity to evaluate the information content of each technique's results in comparison to the others.

Five geophysical techniques were used in the demonstration: electrical conductivity and resistance, magnetic gradiometry and susceptibility, and GPR. These are discussed in detail in the guidance manual developed for this project: *Archaeological Geophysics for DoD Field Use: a Guide for New and Novice Users* (Ernenwein and Hargrave, 2007).

The Bartington Grad601-2 (Figure 8, upper left) is a vertical component dual sensor fluxgate gradiometer. It is designed for archaeological prospection, permits data to be collected rapidly in open areas, and can detect a wide range of feature types based on their magnetic characteristics.

The Geophysical Survey Systems International (GSSI) SIR-3000 Ground Penetrating Radar unit (Figure 8, upper right) is a lightweight GPR system manufactured by Geophysical Survey Systems, Inc. It can be used by one person, particularly when mounted on a three-wheeled cart. Depth prospection varies based on antenna frequency and substrate, but typical investigations range from 0.5 - 3 m in depth.

The Geonics Ltd. EM38-MK2 (Figure 8, lower left) is a compact electromagnetic induction meter that simultaneously measures the quad-phase (conductivity) and in-phase (magnetic susceptibility) components.

The Geoscan RM15-D Resistance meter (Figure 8, lower right) with PA20 probe array and MPX15 Multiplexer allows survey of archaeological sites using a variety of probe configurations and depth settings. For typical archaeological surveys, including those conducted at Los Adaes, the instrument is set up to collect measurements at 0.5 m depth in a three-probe parallel twin array, collecting two side-by-side readings each time the mobile probes are inserted an inch or two into the ground.

Figure 8. Geophysical sensors used at Los Adaes.
Clockwise from upper-left: Bartington Grad-601 magnetic field gradiometer, GSSI SIR-3000 GPR system with 400 MHz antenna, Geoscan RM-15 resistance meter, and Geonics EM38-MK2 conductivity meter.

5.4 FIELD TESTING

5.4.1 NPS Course

The field component of the project's second phase was conducted in conjunction with the NPS's annual 40-hr introductory course on remote sensing held May 18-22, 2009. The field demonstration exposed the participants to all of the steps and procedures involved in future applications of the integrated multi-sensor approach to archaeological site characterization. Mornings were devoted to indoor lectures (held at the National Center for Preservation Technology and Training's [NCPTT] facility at the Northwestern State University campus) on a variety of topics including the role of geophysics in CRM; underlying principles of each method; criteria for site and sensor selection; use of representative sensors; data collection, processing, and interpretation; data integration; and ground truthing. Dr. Michael Hargrave provided an

overview of the ESTCP project's goals and accomplishments to date, Dr. Jack Cothren (CAST) demonstrated *ArchaeoFusion*, and Dr. Jaime Lockhart (Arkansas Archaeological Survey) discussed data that the project team had collected at the site. Representatives of several state, Federal, and tribal agencies who could not be present for the entire NPS course were briefed on the ESTCP project's purpose, approach, and results to date. They were also given a tour of Los Adaes site by Dr. Pete Gregory and Dr. George Avery, archaeologists who had previously excavated at the site, as well as demonstrations of the instruments and data processing.

5.4.2 Ground Truthing

The goal of the ground truthing component of this project was to demonstrate how to use archaeological excavation to test and expand upon interpretations of the site's deposits based on the geophysical survey results. In general, this involved excavating a test unit to determine if an anomaly was correctly identified as a particular type of archaeological feature or deposit. The ground truthing was conducted by Dr. George Avery, director of the CRM program at Stephen F. Austin State University (SFASU), and formerly the resident archaeologist at Los Adaes. Dr. Pete Gregory, who had excavated at the site for a number of years, provided important input during the excavations.

Eighteen units totaling 15 square meters (m^2) were excavated. Interpretations of 11 (73.3%) of the 15 distinct targeted anomalies were confirmed. One other was partially confirmed (a linear feature was found where a structure had been predicted, but the feature was faint and discontinuous), and acceptance of that result would bring the success rate for interpretations to 80%. Based on our experience, this is higher than would be achieved for many sites, particularly prehistoric sites with no apparent architectural remains. Los Adaes exhibits a distinctive settlement plan, and anomalies associated with barracks walls and the palisades were not difficult to interpret. In nearly all cases, the Los Adaes geophysical data allowed very small excavation units to be located directly on the suspected features. Rather extensive excavations conducted prior to this project (Gregory et al., 2006) demonstrate that, without geophysics, far more excavation would be required to collect similar information about the site.

5.5 SAMPLING PROTOCOL

The portion of the Los Adaes site that is accessible for geophysical data collection measures approximately 200 m (NE-SW) by 120 m (NW-SE), with an area of approximately 2.5 hectares. Covering the entire area would be desirable from a research perspective but was not necessary for purposes of this project. Our original goal was to collect high resolution GPR, conductivity, magnetic susceptibility, electrical resistance, and magnetic gradiometry data across an area of 0.5 ha for a 20% sample. We exceeded this goal by surveying 0.68 ha with all instruments, and significantly more area with some but not all instruments. Table 2 lists the area covered by each instrument, and this is shown graphically in Figure 9. The area surveyed was based on the historic maps, and successfully conveyed the fort's distinctive configuration.

Table 2. Area covered by geophysical survey at Los Adaes.

Method	Area Survey (square meters)
Magnetometry	13,200
Electromagnetic induction (magnetic susceptibility and conductivity)	7,200
Resistivity	8,800
Ground penetrating radar	6,800

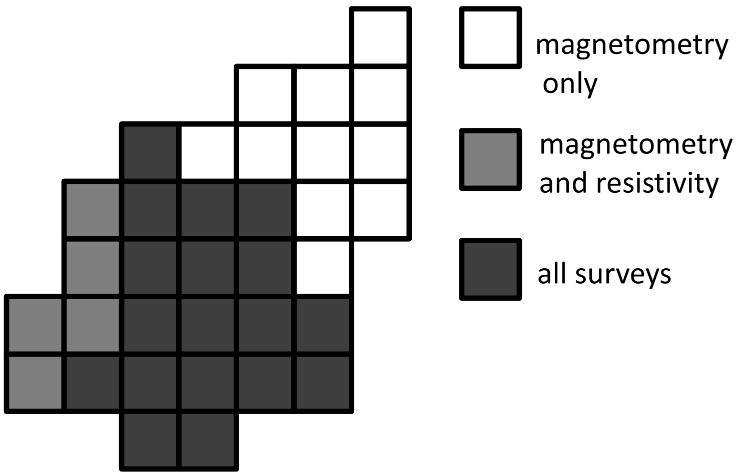

Figure 9. Map showing treatment (survey) locations.
Each square measures 20x20 m.

5.6 SAMPLING RESULTS

In general, the geophysical results (shown in Figures 10, 11, and 12) were excellent. Some of the many anomalies that are readily and reliably interpreted as historic architectural features are labeled (in red) in those figures and explained in Table 3. In comparing these maps, one can easily see how the different sensors detect somewhat different aspects of the archaeological deposits. Overall, the images are as graphically compelling and historically interesting as we had hoped when Los Adaes was selected as the project's demonstration site.

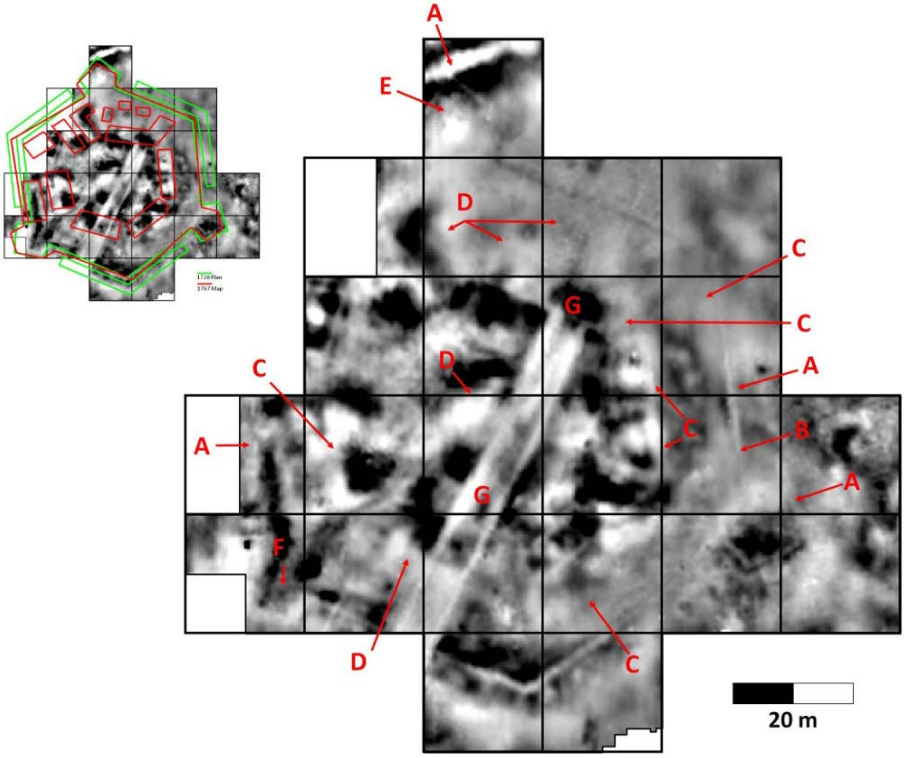

Figure 10. Preliminary interpretation of electrical resistance data prior to excavations. Anomalies labeled in red are discussed in Table 3.

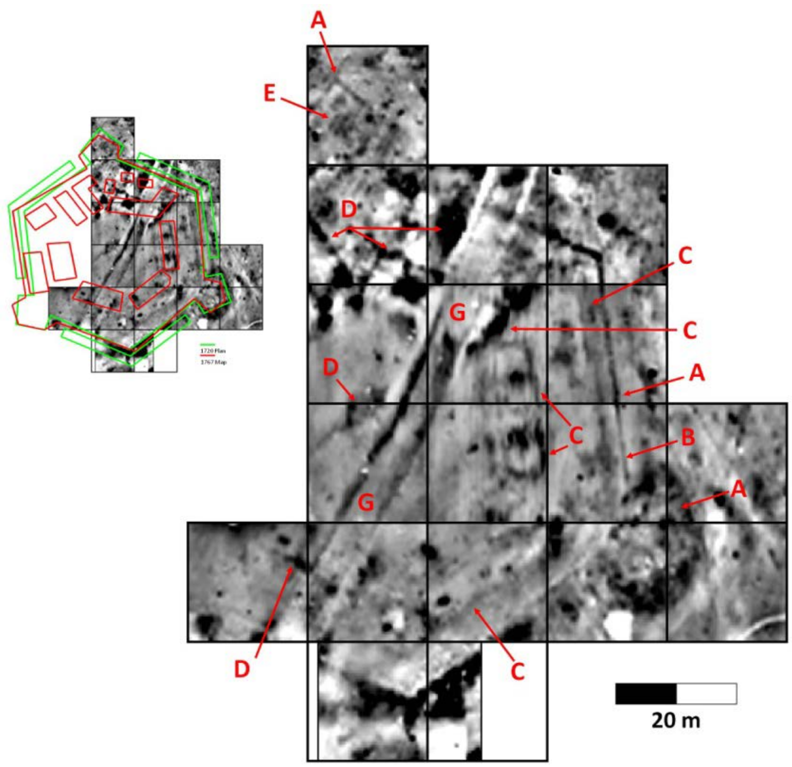

Figure 11. Preliminary interpretation of magnetic susceptibility data prior to excavations.

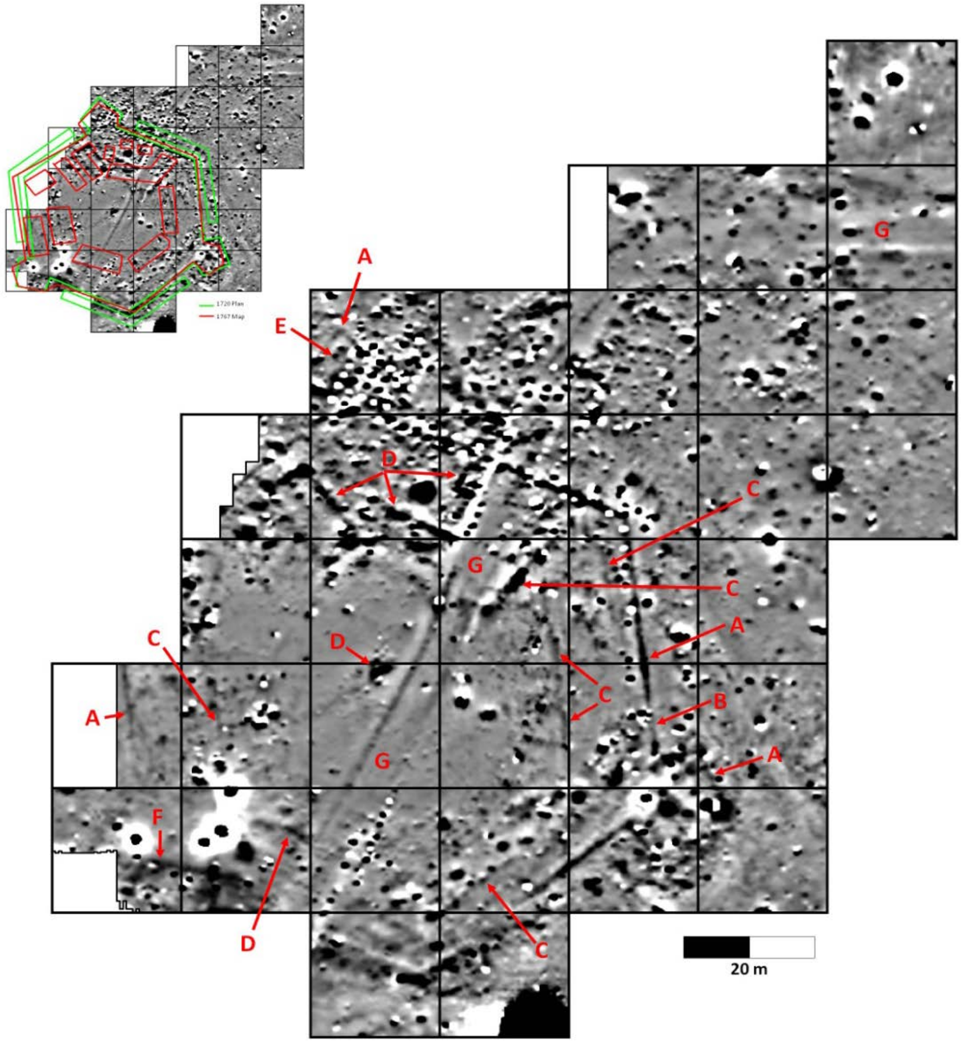

Figure 12. Preliminary interpretation of magnetic gradiometry data prior to excavations.

Table 3. Explanation of anomalies marked in Figures 10, 11, and 12.

A	Anomalies that closely align with the Presidio walls in the 1720 plan.
B	Break in the Presidio anomaly in both magnetic datasets that coincides with an entrance to the inside of the fort in the 1720 plan map.
C	Linear anomalies in both magnetic datasets that coincide with structures in the 1720 plan map (see map at left), but do not appear in the 1767 map.
D	Anomalies associated with structures indicated in the 1767 map, including the governor's house, a chapel, a gunpowder house, and soldier's barracks (see drawing in left panel). Their presence at the expected locations supports previous findings that the 1767 map is accurate in many respects.
E	Possible square structure at the northern bastion, indicated by fine lineations in magnetic susceptibility, and alignments of discrete positive and negative anomalies in magnetometry.
F	possible structure near southeast bastion, not indicated on any maps
G	Historic (post-occupation) parish road and ditch that runs through the center of the fort and to the northeast.

Effective ground truthing can dramatically enhance the interpretability of geophysical data at virtually all sites and therefore is an important component of an integrated multi-sensor approach to characterizing archaeological sites. Various sources of information can be used in ground truthing, including archaeological excavation, aerial and historic photographs, written documents, historic maps, and (for recent impacts) local informants (Hargrave, 2006). In most archaeological situations, ground truthing focuses on the interpretation of discrete geophysical anomalies as particular feature types, or less commonly, deposits (such as midden) or objects (large artifacts).

The two historic (1720 and 1767) maps of Los Adaes have many similarities but also a number of important differences. It was uncertain which map is most accurate, or whether both maps accurately depict the fort at different points in time. Despite this uncertainty, the Los Adaes maps represented a valuable source for hypotheses about the presence, nature, and location of features such as the palisades, bastions, and internal structures, and were very useful in selecting areas for survey and anomalies for ground truthing.

One of the important benefits of the integrated multi-sensor approach is the potential to characterize a site based on geophysical survey and very limited but carefully targeted excavation. Thus, an ancillary goal was to evaluate our interpretations of the geophysical data with as little impact to the site as possible. The project team decided that the excavation of at most 15 m^2 would be a good balance between these goals, and that amount of excavation was acceptable to the State. It was desirable to excavate small units to allow as many anomalies as possible to be investigated. One by one meter units were viewed as the smallest size that would allow a reasonable opportunity to identify the type of features associated with anomalies.

In order to insure that the sample of anomalies chosen for ground truthing would be well-distributed, the fort was divided into "regions" of geophysical interest. These are designated by reference to the nearest bastion or palisade. In some cases, regions are further designated using information from the 1767 map. Portions of the fort that had seen extensive previous excavations and where burials were most likely were intentionally avoided. The nine regions and units excavated to investigate are shown in Table 4.

Table 4. Summary of anomaly interpretations and results of ground truthing.

Region	Unit	Interpretation	Ground Truthing Results
A	1	Structure wall near SW bastion	Partially confirmed. Linear feature present, uncertain if it is associated with a structure
A	2	Structure within or near SW bastion	Rejected. Mounded area associated with bastion, not a discrete structure
A	3	Feature inside a barracks structure	Confirmed. Feature comprised of mounded debris, not a facility
B	4	Feature in/on barracks floor	Confirmed. Collapsed earth oven or brazier platform
B	5	Feature in or near barracks	Rejected. Previous excavation units
C	6	Entry in palisade or old excavation unit	Confirmed. Old excavation unit
D	7	Western edge of a barracks structure, possibly a porch	Confirmed. A prepared surface, possibly associated with the expected porch
D	8	Feature in/on barracks floor	Confirmed by soil cores to be a feature similar to Unit 4

Table 4. Summary of anomaly interpretations and results of ground truthing (continued).

Region	Unit	Interpretation	Ground Truthing Results
D	9	Eastern wall of barracks	Confirmed. Wall trench for barracks wall
E	10	Barracks	Rejected. No evidence of a linear feature
E	10A	No prediction	NA. Prepared surface flanking palisade wall trench
E	11	Eastern palisade	Confirmed. Wall trench with prepared surface on both sides
E	12	Eastern Moat	Confirmed. 75-cm deep deposits including gley soil
	13	Not excavated	
	14	Not excavated	
	15	Not excavated	
	16	Not excavated	
H	17	Discrete feature, type uncertain	Confirmed. Deposit of rich midden
	18	Not excavated	
I	19	Southern palisade	Confirmed. Palisade wall trench
J	20	Wall of barracks or palisade	Confirmed. Barracks wall
J	21	Wall of barracks or palisade	Confirmed. Barracks wall

Eleven of the 18 units initially selected were excavated (Units 1, 2, 3, 4, 6, 7, 9, 10, 11, 12, and 17) and two 0.5x1 m units were excavated as additions to Units 6 and 10, and designated (respectively) as Units 6A and 10A. Units 19, 20, and 21 were added to investigate anomalies relevant to longstanding historical and archaeological questions about the fort (Figure 13).

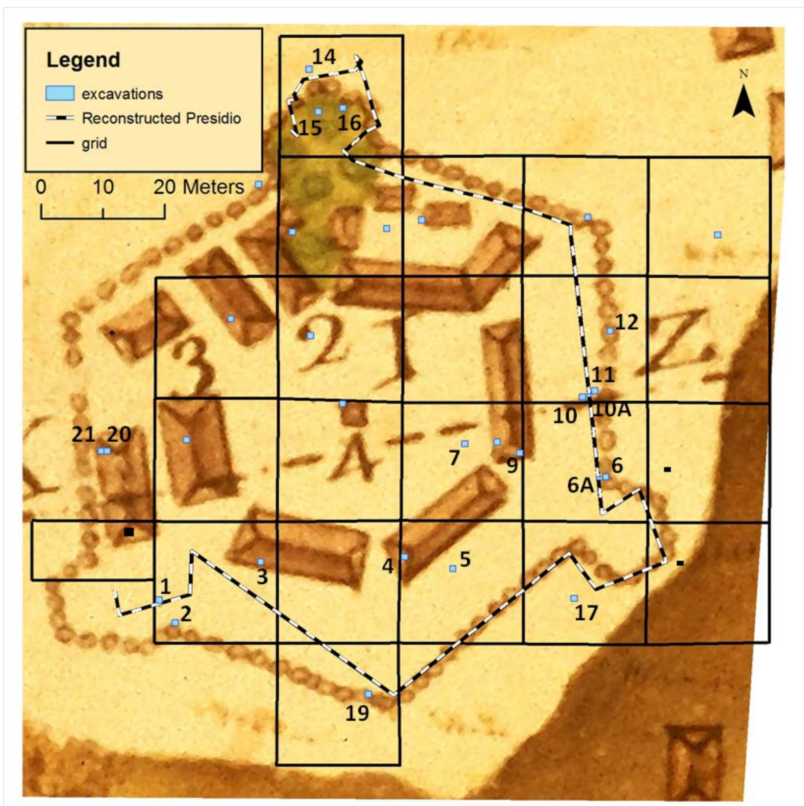

Figure 13. Location of the excavated units (blue) relative to the georeferenced 1767 map. The dashed line shows the location of the horizontal wooden beams that represent the reconstructed presidio. All excavated units are numbered, while those that were planned, but not excavated are shown without unit numbers.

Unit 9 in Region D (Figures 14 and 15) provides a good illustration of the ground truthing process and results. The Region D anomalies were interpreted as features associated with a barracks structure depicted on both of the historic maps (Figure 13). Unit 9 focused on a strong linear magnetic susceptibility anomaly interpreted as the eastern wall of the barracks. Two levels were excavated and a linear feature was observed along the unit's west wall at 20 cm below surface (bs). The feature may represent the wall trench for the barracks wall. Unit 9 had the greatest diversity of metal artifacts recovered during this project, including hand wrought nails, gun parts, horse gear, and lead shot. These findings are consistent with the unit being located inside a barracks, confirming that the anomaly investigated by Unit 9 had been correctly interpreted.

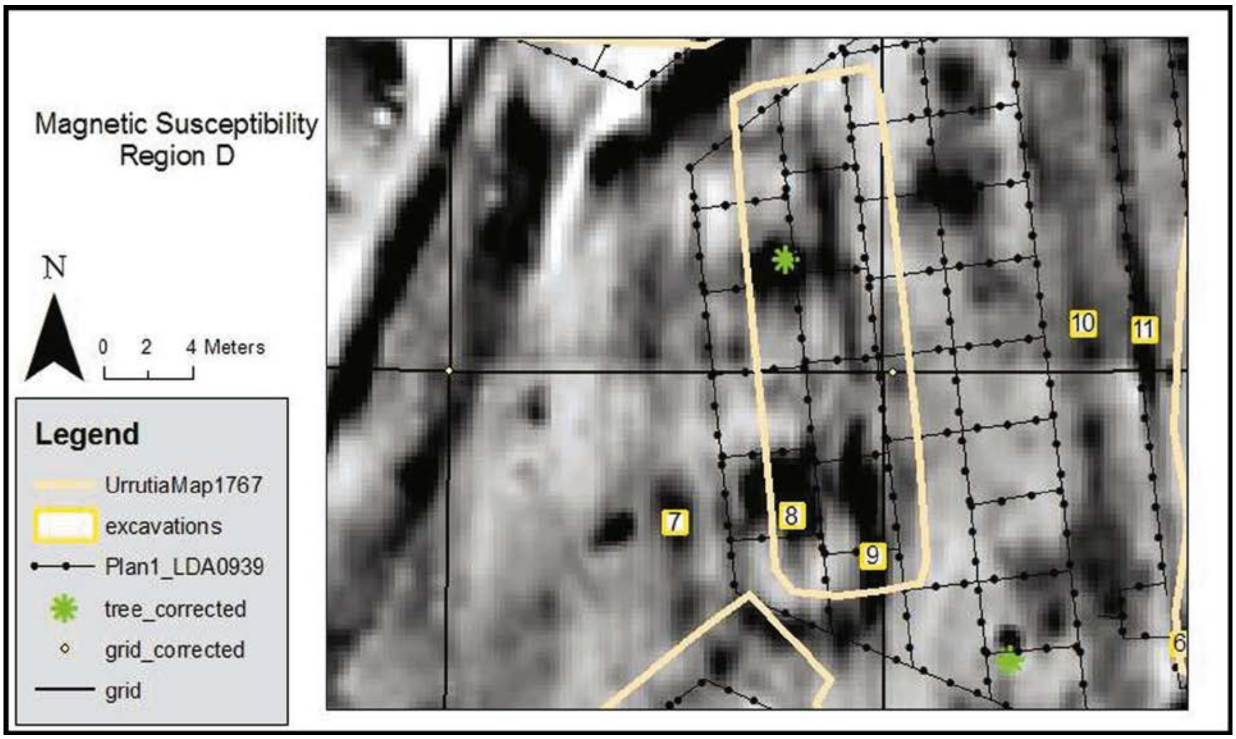

Figure 14. Magnetic susceptibility image of Region D showing the location of Units 7-11.

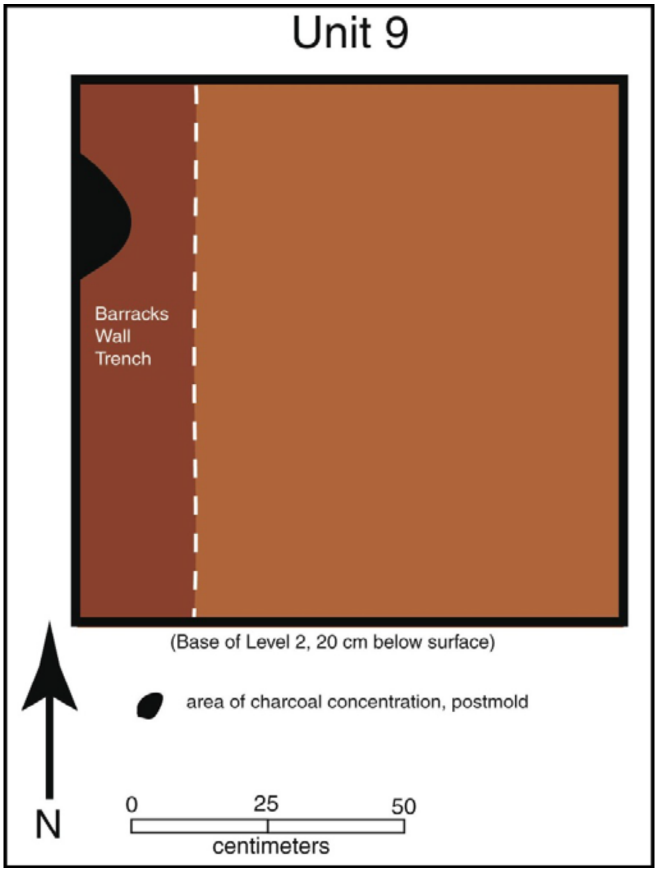

Figure 15. Wall trench associated with eastern wall of a barracks detected in Unit 9.

Table 4 summarizes the interpretations of the geophysical anomalies and results of ground truthing. Excavation units were targeted on 15 anomalies (totaling 15 m^2). In terms of ground truthing methods, our use of very small (1x1 m) excavation units supplemented by soil cores was highly effective. Where soil probes can be excavated and color or texture differences associated with feature fill can be detected, they can dramatically reduce the cost and/or increase the information return of ground truthing excavations.

Interpretations of 11 (73.3%) of the 15 were confirmed. One other was partially confirmed (a linear feature was found where a structure had been predicted, but the feature was faint and discontinuous), and acceptance of that result would bring the success rate for interpretations to 80%. Based on our experience, this is higher than would be achieved for many sites, particularly prehistoric sites with no apparent architectural remains. Los Adaes exhibits a distinctive settlement plan, and anomalies associated with barracks walls and the palisades were not difficult to interpret. Overall, the Los Adaes geophysical data allowed very small excavation units to be located directly on the suspected features. Without geophysics, far more excavation would be required to collect similar information about the site. Proof of this is seen in the large number of units excavated in previous efforts to locate features depicted in the historic maps (Gregory et al., 2004).

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6.0 PERFORMANCE ASSESSMENT

Two performance assessments were conducted but, as explained previously, Assessment 1 results were compromised by inadequate sample size. Here we focus on the analysis of data used in Assessment 2. Most of the respondents had first-hand experience in using *ArchaeoFusion* during Assessment 1. An abbreviated version of the Assessment 1 tutorial and exercises was made available to the Assessment 2 participants. Users could easily answer these questions based on experience they already had using *ArchaeoFusion*, or by following along with the tutorial, which simultaneously helped them learn the software. Complete details (including the results and responses for each participant) are available in the project's Technical Report. The performance objectives are stated below as they were originally defined followed by a summary of the survey responses. The actual survey questions are provided below (Section 6.9), and results are tabulated in Table 5.

Table 5. User responses to questions 1-8 in Assessment 2.

Question (Objective)	Disagree	Neutral	Agree	Response Count
1 (1)	0	0	**100% (14)**	14
2 (2)	0	0	**100% (14)**	14
3 (3)	0	8% (1)	**92% (12)**	13
4 (5)	31% (4)	23% (3)	**46% (6)**	13
5 (7)	0	46% (6)	**54% (7)**	13
6 (6)	0	0	**100% (13)**	13
7 (4)	8% (1)	31% (4)	**61% (8)**	13
8 (8)	0	14% (2)	**86% (12)**	14

6.1 OBJECTIVE 1

"Non-integrated multi-sensor surveys provide more useful information than single sensor surveys."

All participants agreed that, in general (regardless of software), multiple surveys, even when not integrated, provide more useful information than single sensor surveys.

6.2 OBJECTIVE 2

"*Data integration increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets."*

Participants were asked "In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc.) increases the potential for detecting archaeological features in geophysical data when using multiple but non-integrated datasets. Response choices were a) strongly disagree, b) disagree, c) neutral, d) agree, or e) strongly agree. *100% of Assessment 2 participants agreed (chose d or e).*

6.3 OBJECTIVE 3

"ArchaeoFusion allows all users to effectively integrate data from multiple sensors."

Ninety-two percent of respondents agreed. Most respondents left very positive remarks about this feature of *ArchaeoFusion*. For example, respondent 4 remarked "The main benefit of *ArchaeoFusion* is that it gives the user the ability to integrate data from multiple geophysical data types using a straight-forward and user-friendly interface." No respondents disagreed with the objective statement, but one did mark "neutral," and made the comment that "I used *ArchaeoFusion* briefly, but ran into problems trying to process data (getting errors from the Matlab substrate). …aside from the problems…, I found the software fairly easy to use." Clearly this respondent did not agree with the objective statement because he or she had not used the software enough to evaluate the integration capabilities.

6.4 OBJECTIVE 4

"Data processing using ArchaeoFusion is faster and easier than processing using COTS software."

Sixty-one percent of respondents agreed.

6.5 OBJECTIVE 5

"Data from all major sensor types can be adequately processed using only ArchaeoFusion."

Forty-six percent of the participants agreed. Those whose responses to this statement were neutral or negative (did not agree) either encountered software bugs that had not been identified in the beta test and subsequent development, or were users of dedicated GPR software. The latter viewed GPR processing as a weak area for *ArchaeoFusion* (those dedicated software are, however, designed to process *only* GPR). On balance, *ArchaeoFusion* is capable of processing all of the main types of geophysical data, but for many users it is not adequate for their level of need for GPR processing. We interpret this to mean that the software satisfies the needs of this project, but does not provide enough sophisticated processing capabilities for advanced GPR users.

6.6 OBJECTIVE 6

*"*ArchaeoFusion *preserves data resolution."*

All of the respondents agreed that *ArchaeoFusion* preserves data resolution.

6.7 OBJECTIVE 7

*"*ArchaeoFusion *reduces the time needed and increases the quality and consistency of metadata for geophysical data."*

Fifty-four percent of the respondents agreed that, in comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers

(i.e., GPR, electromagnetic induction [EMI], magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. Those respondents included the most experienced participants. The remaining 46% of respondents marked "neutral" to this statement. Further communication revealed that most of the respondents who marked "neutral" did not have experience with using multiple software packages to process and integrate geophysical data from different instruments and manufacturers, and so could not honestly agree with the statement.

6.8 OBJECTIVE 8

"Ground truthing enhances the usefulness of geophysical data."

Eighty-six percent of the respondents agreed that ground truthing enhances the usefulness of geophysical data.

6.9 SURVEY QUESTIONS

Below are the actual questions asked by the survey in Assessment 2. These questions were ordered to be consistent with the tutorial, and do not follow the same order as the performance objectives.

1. In regards to archaeological geophysics in general (regardless of software): multiple surveys, even when not integrated, provide more useful information than single sensor surveys. (Objective 1)
2. In regards to archaeological geophysics in general (regardless of software), data integration (including overlaying layers in GIS, using transparent layers, mathematical and statistical combinations of data, etc) increases the potential for detecting archaeological features in geophysical data, when compared to multiple but non-integrated datasets. (Objective 2)
3. *ArchaeoFusion* allows users to effectively integrate data from multiple sensors (i.e., overlays, translucent overlays, band calculator, principle components analysis, and k-means cluster analysis). (Objective 3)
4. Data from all major sensor types can be adequately processed using *ArchaeoFusion* alone. (Objective 5)
5. In comparison to using multiple software packages to process and integrate geophysical data from different instruments and manufacturers (i.e., GPR, EMI, magnetometry, and resistivity), *ArchaeoFusion* reduces the time needed and increases the quality and consistency of metadata for geophysical data. (metadata are information about your data, such as what instrument was used to collect it, the start corner and direction for the survey, etc.). (Objective 7)
6. *ArchaeoFusion* preserves data resolution. (meaning, that when you are finished processing your data, you can always revert to the original data with the original data density). (Objective 6)

7. Data processing using *ArchaeoFusion* is faster and easier than processing using other COTS software. (Objective 4)
8. Ground truthing (test excavations to evaluate interpretation of geophysical data) enhances the usefulness of geophysical data. (Objective 8)
9. Please comment on the benefits of *ArchaeoFusion* and describe any shortcomings that you perceive.

Table 5 summarizes user responses to questions 1-8. The categories “strongly disagree” and “disagree” in the original survey were combined, as were “agree” and “strongly agree.” Comments written in question 9 are given along with individual survey results in Appendix B of the Final Report (Ernenwein et al., 2012).

7.0 COST ASSESSMENT

7.1 COST MODEL

Table 6 provides a cost model for implementing the integrated multi-sensor geophysical approach. The costs shown are based on the demonstration conducted at Los Adaes. Some cost elements that had been partially subsidized by the performer's institution were corrected using appropriate data (for example, labor was calculated using the national average rate for archaeologists reported in a survey done by the Society for American Archaeology).

Table 6. Cost model for implementation of integrated multi-sensor geophysical approach.

Cost Element	Data Tracked During Demonstration	Estimated Costs
Sensor procurement[a]		$80,000 (4 @ $20,000 each)
Installation costs[b]		$26,448
Sensor consumable[c]	0	0
Operation costs[d]	$61,359	
Maintenance[e]		0
Sensor lifetime[f]		10 years (minimum)
Total cost		$106,448

[a]Observed costs ranged between $18,593 and $22,420. All other sensors range between approximately $15,000 and $25,000. $20,000 is used as an estimate for all sensors because decisions about which to purchase should be made on performance characteristics relative to local conditions, not cost.
[b]Installation costs for four sensors include *ArchaeoFusion* (free to DoD), graphics software ($700), training labor, NPS class tuition, and temporary duty travel (TDY) costs (40-hr course plus travel).
[c]No sensor consumables. Equipment such as survey ropes and flags have negligible costs and can be reused for years.
[d]Operation costs pertain to the amount of geophysical survey and ground truthing excavation actually conducted during the demonstration, which is equivalent to the NRHP evaluation of one large and complex archaeological site. Actual labor rates (partially subsidized by the project and performer's institutions) were adjusted up to estimated national average labor and over-head rates.
[e]No maintenance costs projected for 10 years of sensor use.
[f]Estimated lifetime based on author's observation of no sensor failures over a 10-year period.

7.2 COST DRIVERS

Cost drivers for implementing the integrated multi-sensor approach include sensors, *ArchaeoFusion* software, supplemental graphic software, temporary duty travel (TDY), tuition, and labor associated with training, and labor associated with implementation of the approach (actual use of the sensors).

Purchase of the sensors is the single largest cost component. Most sensors with broad archaeological applications cost between $15,000 and $25,000. Here all sensors are estimated at $20,000 to underscore the importance of selecting sensors based on factors that will determine their effectiveness in use. These factors include their suitability for the soil, vegetation, surface disturbance, and other conditions that typify a particular installation's sites, as well as the nature of its archaeological deposits. Installation archaeologists will be aware of the latter. Prior to purchase, installation users should consult with state or Federal archaeologists who have extensive first-hand experience in using geophysical sensors for archaeological applications, and who can be trusted for impartial advice (the authors can identify many such individuals). Individuals with geophysical expertise in fields other than archaeology will often be unfamiliar with the small size, very low contrast, and issues such as clutter and equifinality that characterize

many archaeological deposits, and may therefore inadvertently provide very poor advice on sensor selection.

The cost for implementing the approach, \$106,448, includes the purchase of four sensors. This number would provide excellent versatility and would lessen the risk of acquiring only one or two sensors that are not well-suited to local conditions. Labor and TDY costs associated with training in sensor use, attending the week-long NPS introductory class, and purchasing a supplemental graphics software totals \$26,448. Achieving a reasonable level of competence in sensor use, data processing, and interpretation is as important as sensor selection. Given frequent turnover in CRM personnel at installations, the ideal situation is for at least two individuals to adopt geophysics as a primary skill (although they would also perform other duties), thereby ensuring continuity. Competence can best be achieved by working with a mentor (often an instructor met at the NPS class). *ArchaeoFusion* makes it easy to exchange processed data via email, and to reprocess data based on input from the mentor.

Implementation costs (\$61,359) are based on the costs monitored during the demonstration at Los Adaes. Those costs include geophysical survey, data processing and interpretation, ground truthing excavations, and report preparation needed to evaluate the eligibility status of a very large, complex site (comparable to Los Adaes). Most archaeological sites are substantially smaller and less complex, and their costs would be proportionately less. Conducting the field demonstration at Los Adaes also exemplifies how geophysical survey could provide the basis for data recovery needed to mitigate the destruction of a relatively large, complex site. Such mitigation would, however, still require substantially more excavation than the 15 m^2 excavated to ground truth interpretations of anomalies at Los Adaes.

Based on our long-term personal experience, one can expect no maintenance costs over a 10-year period. There are no sensor consumables, and field equipment used in conjunction with the sensors has negligible costs (nylon reel tapes and ropes marked at 1-m intervals, chaining pins and plastic pin flags).

7.3 COST ANALYSIS AND COMPARISON

Costs for implementation assume that geophysical survey will be conducted only at sites where conditions are reasonably favorable. Detailed guidance on how to recognize favorable conditions is provided by a manual prepared as part of this project (Ernenwein and Hargrave, 2007). In brief, favorable conditions include the absence of 1) vegetation that would preclude systematic movement of the sensors across the site along transects spaced at not more than 1 m, 2) disturbance that would significantly impact sub-plow zone soils (bulldozing, deep rutting, extensive tree-tips, 3) recent trash or other debris that would represent extensive clutter in geophysical imagery, and 4) extremes in soil moisture (which affect the various sensors differentially). Cost estimates also assume that 5) those who collect, process, and interpret the data have developed a reasonable level of competence and 6) archaeological deposits that can be detected by competent survey are present (at some of the installation's sites).

A life-cycle analysis of costs was not conducted because the sensors are typically highly durable. It is reasonable to assume that no significant repairs will be needed over a 10-year period. Opportunities for sensor upgrades may arise, but these would presumably only improve their

performance and thus, the cost effectiveness of the integrated multi-sensor approach. *ArchaeoFusion* software will be distributed by CAST at no cost to DoD users for 5 years following completion of this project. CAST is developing plans to sell *ArchaeoFusion* to non-DoD users, with the resultant funds being used for maintenance and periodic upgrades. There is little risk that *ArchaeoFusion* will cease to be available.

This project's technical report presents a detailed comparison of the cost of evaluating the Los Adaes site's eligibility for nomination to the NRHP using the integrated multi-sensor approach with a traditional approach based on hand excavation. The former approach, as demonstrated by this project, would cost $61,359. In fact, the demonstration involved significantly more geophysical survey and a little more ground truthing than would have been needed. We estimate that the integrated multi-sensor approach could have been used to evaluate the demonstration site's NRHP eligibility for $30,680. In comparison, the traditional approach would have required twice as much excavation (30 m^2), costing an estimated $88,798, and would have been much more invasive yet much less informative about the site.

Previous excavations in one portion of Los Adaes (63 m^2) were used as the basis for estimating the costs of mitigating the site. Using the demonstration project's cost structure, that amount of excavation was estimated to cost at least $151,213 (realistically, much more excavation would be needed to mitigate the destruction of a site as large and complex as Los Adaes). For the sake of this example, however, that amount ($151,213) would be adequate to purchase four sensors, pay for training in their use, conduct extensive geophysical survey, and still leave $22,817 to fund carefully targeted ground truthing excavations. This example shows the clear cost benefits of implementing the integrated multi-sensor geophysical approach to characterizing archaeological sites.

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8.0 IMPLEMENTATION ISSUES

8.1 USEFUL INFORMATION SOURCES

Several books provide reasonably non-technical overviews of the geophysical methods relevant to archaeology. One that will be particularly useful for installation personnel who will become geophysical technicians is *Remote Sensing in Archaeology: An Explicitly North American Perspective*, edited by Jay K. Johnson (University of Alabama Press, Tuscaloosa, 2006). Each commonly used geophysical method is described by top experts and this is one of the few sources that also discusses methods and approaches for ground truthing.

A second source that will be very useful to installation decision makers as well as field technicians is the guidance document developed for this project: *Archaeological Geophysics for DoD Field Use: a Guide for New and Novice Users* (Ernenwein and Hargrave, 2007). It begins with a discussion of fundamental concepts (contrast, noise, clutter, data density, and resolution) that provide a basis for understanding why a particular sensor will work well at some sites and not others, why some features can be detected and others cannot, and why some sites are good candidates for the integrated multi-sensor approach and others are not. The volume introduces each of the main methods, but focuses more than other technology overviews on critical issues that CRM team leaders should consider *before* they purchase sensors.

Other information sources include Gaffney and Gater (2003), Witten (2006), and David Clark's 2001 classic *Seeing Beneath the Soil* (complete information can be found in the References Cited section).

8.2 REGULATIONS

The only regulations of concern to archaeological users of geophysical equipment are the U.S. Federal Communications Commission (FCC) regulations on the use of ultra-wideband (UWB) sensors, particularly GPR. FCC regulation 15.525(c) (updated in February 2007) requires GPR users to coordinate the use of their equipment, comply with any constraints on equipment usage resulting from this coordination, and supply their name, address and other pertinent contact information, the desired geographical area(s) of operation, and the FCC identification number and other nomenclature of the GPR device. This regulation caused considerable concern among GPR users when first enacted, but it has since been recognized that it does not limit archaeological applications. Installations can secure up-to-date information about this regulation from sensor manufacturers. Users will also need to contact the appropriate installation offices to determine if there are any local restrictions on the use of GPR sensors in the immediate vicinity of sensitive communications equipment. The authors have not encountered any such restrictions in their previous work on a number of Army installations.

8.3 END USER CONCERNS, RESERVATIONS, AND DECISION MAKING FACTORS

Informal conversations with many attendees at NPS classes over the years indicate that many CRM units would like to adopt geophysics but are not able to afford sensor purchase costs. The extent of previous investigations at Los Adaes makes it clear that the traditional approach to

evaluating reasonably complex sites has very high labor costs. This is particularly true for sites where mitigation involves very extensive data recovery. The larger and more complex a site is, the greater the opportunity to use data on feature location derived from geophysical survey to reduce the amount of excavation needed. Thoughtful answers to the following questions will help installation CRM personnel make decisions about adopting the integrated multi-sensor approach or continuing exclusively with the traditional approach.

1) Does the installation include many sites not yet evaluated for NRHP eligibility that are likely to have discrete subsurface features? This can be answered by archaeologists with a substantial knowledge of the region. If the answer is yes, proceed to 2). If you remain uncertain about the answer and are still interested in geophysics, we suggest you contract for a partial geophysical survey of one or two of your larger, more complex sites to determine if features are present and can be detected before you invest in sensors.

2) Are dozens of your unevaluated sites relatively large (1 ha or more) and complex (moderately abundant artifacts, evidence for several occupational components)? If yes, proceed to 3).

   Our cost analysis demonstrates that the integrated multi-sensor approach is substantially more cost effective than a traditional NRHP evaluation for large, complex sites. The ratio of benefits to costs decreases as one considers increasingly small, less complex sites.

3) Do many of those sites have vegetation that would permit geophysical survey without extensive clearing? Refer to Ernenwein and Hargrave (2007) for guidance on evaluating site suitability for geophysical survey.

4) Would funding circumstances permit the CRM program to invest in two or three sensors ($40,000 to $60,000) over the course of one or several years to establish an in-house capability in return for expected substantial decreases in future contracts to evaluate the NRHP status of sites? If yes, refer to Ernenwein and Hargrave (2007) for detailed guidance on selecting sensors. If not, consider contracting for a geophysical survey of several promising sites, and if results are positive, use them to bolster your rationale for an in-house geophysical capability.

5) Does the installation have at least a few large, complex sites that represent very serious obstacles to training or infrastructure expansion? The mitigation (by large scale data recovery) could offset the costs of establishing an in-house geophysical capability. An effective approach would be to hire an experienced practitioner to collect, process, and interpret the data while training installation personnel.

An in-house geophysical capability would not be cost effective for all installations. Those that have primarily small sites and/or sites that apparently have few discrete features (e.g., Fort Bragg, North Carolina), very shallow rocky soil (e.g., Fort Leonard Wood, Missouri), or where effective work by the CRM program in past years has minimized limitations on training posed by archaeological sites might be best served by the traditional approach. Even installations that develop an in-house geophysical capability would probably still use the traditional approach for many small sites, sites with dense vegetation, or heavy surface disturbance. Maximum cost

effectiveness could be achieved by an experienced manager who learns when the integrated multi-sensor approach will yield its benefits, but who does not systematically apply it in all situations.

This project has demonstrated how the integrated multi-sensor approach—in comparison to traditional practices—yields much greater information about subsurface features and substantially lower labor costs. One limitation in the demonstration has been our focus on a single site. We selected Los Adaes as the project demonstration site because it would arouse the interest of a very broad audience of archaeologists, historians, and other CRM professionals who might not otherwise consider adopting the integrated multi-sensor approach. Los Adaes' very early architecture also distinguishes it from most of the sites on military installations. Verifying the existence of major features shown on the two historic maps required more excavation than would characterize most NRHP eligibility evaluations, and resulted in estimated costs higher than would actually be expended on sites located on military installations. Most installation cultural resource (CR) managers would do enough excavation to verify the site's eligibility, define a buffer around it, and recommend avoidance.

Basing the cost model on a number of sites would have been preferable, but was not really essential. Installation CR managers and their supervisors can replicate our cost comparison using an approximation of their average expenditures to evaluate the NRHP status of small non-complex, intermediate, and large, complex sites. They should compare the costs of the integrated multi-sensor and traditional approaches in terms of both cost and information return. Installation personnel should also consider that the integrated multi-sensor approach makes the mitigation of sites whose presence is highly problematic economically feasible. We are not aware of an approach for calculating the costs associated with the need to avoid sites during military training, but those costs are certainly real, both in dollars and in loss of training realism.

8.4 PROCUREMENT ISSUES

ArchaeoFusion will be available from CAST at no cost to DoD users for the next 5 years. The purchase cost of *ArchaeoFusion* for non-DoD customers has yet to be determined. The software will be ready for distribution by the end of 2011. We are aware of no other procurement issues. All of the sensors used by archaeological practitioners in the United States are commercially available (COTS).

8.5 REVISED TECHNOLOGY INFUSION PLAN

Our original technology infusion strategy focused on demonstrating how DoD CRM programs could achieve the cost and performance benefits by means of a "direct" approach—purchasing sensors, training personnel, and integrating the IMA into regular use. Unfortunately, this 5-year project has spanned a dark period in the nation's economy, and a full recovery is not yet in sight. Expected reductions in funds available for managing cultural resources may delay the direct adoption of the technology by DoD. Despite this situation, we envision at least two ways that DoD installations could realize the cost and information benefits of the approach. In the recent past, DoD installations have often developed multi-year indefinite delivery, indefinite quantity (IDIQ) contracts with CRM providers. Installations are increasingly using national IDIQ contracts with large firms (who sometimes partner with smaller, more specialized firms). While

this shift may decrease an installation's potential to contract with some of the smaller, local firms they have used in the past, contracting with large firms may create more of an opportunity to adopt the integrated geophysical approach. The expectation of multi-year awards (IDIQ contracts often have the option to be continued for 5 years) might encourage larger firms to make the investment in the multiple sensors and staff training needed to adopt the integrated multi-sensor approach. Installation CRM programs could encourage this effort by requesting or, in carefully chosen situations, requiring use of the geophysics in evaluating and mitigating sites.

Unless they happen to have substantial experience in using geophysical methods, the installation personnel should consult with experienced geophysical practitioners associated with DoD research labs (e.g., Engineer Research and Development Center [ERDC]), Corps of Engineer Districts, or trusted private sector consultants. (The authors can identify many such individuals and organizations). Important issues to be considered include the selection of installations and individual sites where geophysical methods are likely to be successful, and that are large enough to ensure the cost and information return benefits. Another important issue is the selection of primary and secondary instruments that are appropriate to the natural and cultural characteristics of installations and sites. Installation CRM personnel interested in the integrated multi-sensor approach should read the guidance document prepared by this project (Ernenwein and Hargrave, 2007), which addresses these and other relevant issues. Installation personnel would also be wise to consult with their State Historic Preservation Office early in the process. Many SHPO personnel are not yet knowledgeable about geophysics, but awareness of its benefits relative to traditional archaeological approaches is steadily growing. SHPO personnel are likely to be particularly interested in the extent to which ground truthing will be used to verify or refute interpretations based on the geophysical survey results. Installation personnel could help SHPO reviewers gain confidence in the reliability of geophysics by including more ground truthing in their initial projects than might otherwise be required.

One issue that has frequently arisen in discussions about the adoption of geophysics in CRM is the concern that small firms would not be able to compete with larger companies that can afford to invest in multiple sensors and specialized personnel. One way to address this concern is to encourage SHPO reviewers to view the integrated geophysical approach as an alternative to—*not* a replacement of—traditional archaeological approaches. If both approaches are available, archaeologists will soon learn how to use the approach that will best achieve the short term goals of individual projects and the longer term goals of cost avoidance and increasing the potential for removing sites that represent obstacles to training by means of professionally responsible mitigation.

A second strategy for securing access to the integrated multi-sensor approach would be for multiple installations to share equipment and expertise. There may well be contractual or other bureaucratic restrictions on personnel stationed at (and paid by) one installation assisting in CRM activities at a second installation. Those limitations could probably be overcome with proper planning and coordination with contracting officers and appropriate managers. If so, installations could benefit from the expertise of other Federal CRM employees for little more than the associated TDY costs. Representatives of the CRM programs at all of the participating installations should become familiar with the issues and information mentioned above, particularly the selection of sites amenable to the geophysical approach. All participating

programs should assure themselves that the individuals who will collect, process, and interpret the geophysical data have acquired adequate training. Use of *ArchaeoFusion* can expedite that, but acquiring adequate expertise demands both interest and effort. Experienced DoD geophysical practitioners could help verify the competence of novice practitioners by reviewing their processed data, interpretations, and proposed ground truthing strategies.

To ensure the success of both of these strategies, the DoD CRM community must take care to avoid a mistake that has slowed the adoption of geophysics by U.S. archaeologists. We should not expect the approach to be the proverbial “silver bullet” for the funding and other challenges that confront CRM. Cost and information return benefits will be realized by those who choose sites wisely, acquire a modest but adequate level of expertise, maintain both professional enthusiasm and skepticism, and who seek advice from, and share their successes and failures with colleagues. Using geophysics at sites that are not suitable, using inappropriate instruments or survey designs, allowing incompetent individuals to collect, process, and interpret data, and failing to develop ground truthing strategies that are well integrated with the geophysical survey and characteristics of the local archaeology have led numerous archaeologists to try geophysics *only once*. Careful reading of this project’s guidance document (Ernenwein and Hargrave, 2007) and consultation with competent mentors and colleagues can prevent nearly all failures.

To help ensure that the adoption of the integrated multi-sensor geophysical approach is successful, several modest investments need to be made by the CRM community:

1. Sponsor web-based training courses in the use of *ArchaeoFusion*. In addition to working with the software, such courses could also include discussion of issues covered by the guidance document already referenced (Ernenwein and Hargrave, 2007).
2. Sponsor 1-day classes at professional conferences such as the annual meetings of the Society for Historic Archaeology and Society for American Archaeology. Those organizations already offer a number of courses (in topics such as archaeological chemistry, Native American consultation, and the Section 106 process) each year immediately prior to or during their conferences. Prospective instructors are often already in attendance, making additional costs modest. Such classes should be directed at both geophysical practitioners and SHPO and other agency personnel who need to be able to differentiate competent from incompetent geophysical applications.
3. Sponsor an informal vetting process, wherein experienced DoD geophysical practitioners work with trainees for a day or two in the field to ensure that they have achieved the basic knowledge and experience to conduct their own surveys. These practices will go a long way towards ensuring that the DoD CRM community will realize the benefits of the integrated multi-sensor approach.

Additional measures that will aid the adoption of the multi-sensor geophysical approach using *ArchaeoFusion* will be the free availability of the software to DoD personnel, and free time-limited *ArchaeoFusion* licenses for classrooms teaching geophysics. These combined with online classes may foster the adoption of the approach to a broad audience of CRM practitioners and young archaeologists who are still in school and that will soon enter the CRM workforce.

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APPENDIX A

POINTS OF CONTACT

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